PROJECTS

THE ACCELERATOR TEST FACILITY

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The interest in Free-Electron Lasers operating in very short wavelengths, down to hard x-rays, is growing.

A key aspect of the mission of Brookhaven National Laboratory (BNL) is to construct, operate and use large facilities for the breadth of scientific disciplines supported by the Department of Energy. An important component of the success of BNL comes from innovative accelerator R&D, since new accelerator technologies hold the key to new achievements in applications and user facilities. We are now facing the emergence of a new technology: very high-brightness electron beams. This technology has far-reaching implications for x-ray sources and other applications.

Part of the NSLS' mission is to develop radiation sources for the future. The NSLS has been the first light source to pursue the development of Free-Electron Lasers (FELs) as the next generation synchrotron light sources. BNL has been a leader in the national effort on FEL development, hosting the workshops "Prospects of a 1 Å FEL" in 1990 and "Towards Short Wavelength FELs" in 1993, as well as developing its Conceptual Design Report and pursuing subsequent efforts to develop a national collaboration in the field. In the past decade, the NSLS made significant contributions to the science of FELs sucha s the theories on Universal Scaling of exponential regime FELs in 3-D, the High-Gain Harmonic Generation and beam conditioning. Experimentally we have led in the development of record high-brightness electron beams and methods of measurements of these and the shortest wavelength measurement of Self Amplified Spontaneous Emission (SASE).

The NSLS developed a vision of the next generation of light sources and is assembling the beam physics and technology to make this happen. Emphasizing single-pass FEL amplifiers, which have advantages over oscillators in the short wavelength regime where cavity mirrors are unavailable, the NSLS developed the High-Gain Harmonic-Generation (HGHG) FEL approach as a the best strategy to build a high quality short wavelength FEL. High-brightness electron beam R&D was undertaken in a major way, since this is the key to achieving short-wavelength FELs as well as other significant applications, such as linear colliders, laser accelerators and more. The BNL Accelerator Test Facility (ATF) is the proving ground for these advances.

What is the ATF? First and foremost, it is a user facility for accelerator and beam physicists, operated by the NSLS and the BNL Center for Accelerator Physics. There is no other proposal-driven, peer-reviewed facility like the ATF that is dedicated for long range R&D in accelerator and beam physics.

The ATF has a unique combination of a high-brightness electron beam, synchronized-high-power lasers, a well-equipped 3 beamline experiment hall, and advanced diagnostics and control systems. The ATF's program in RF guns is recognized internationally. With its synchronized lasers and electron beams of unprecedented brightness, the ATF is an ideal site for R&D on advanced accelerator concepts, FELs, femtosecond X-ray sources and similar topics. These tools have been crucial to recent ATF record achievements: the measurement of Self Amplified Spontaneous Emission (SASE) at 1 (m and 0.63 (µm, and laser acceleration by the Inverse Cerenkov and Inverse FEL mechanisms.

The generation and acceleration of very high brightness electron beams is a key technology for short wavelength FELs as well as other applications, including linear colliders, Compton backscattering for the production of femtosecond x-rays, laser accelerators and more. A high brightness means that the electron bunch has a high density in 6-D phase space. To achieve high brightness beams, it is necessary to do the following: 1) Master the production of such beams in special electron guns. 2) Develop diagnostics that provide information of the 6-D distribution of electron bunches on sub-picosecond time scales. 3) Control the 6-D distribution of the bunch in various ways. 4) Accelerate the electrons to high energies without diluting the brightness.

NSLS scientists working at the ATF measured the slice emittance of a 10 ps electron bunch with a 1 ps resolution, achieved a record high 6-D electron phase-space density and directly measured electron bunching on an optical scale. Another diagnostic under development at the ATF is tomographic analysis of the distribution of electrons in transverse phase space. The next step is to pursue non-linear emittance compensation. Laser photocathode RF guns have provided a major improvement in the brightness, which was further enhanced by the introduction of (linear) emittance compensation. The dream of another major improvement by the introduction of non-linear corrections has been brought within reach by the development of the slice-emittance diagnostic and phase space tomography.

Key to our plans is the development of sub-harmonically seeded FELs in which harmonic generation converts a laser seed to much shorter wavelength radiation. A proof-of-principle High-Gain Harmonic-Generation (HGHG) FEL experiment is now being executed at the ATF in the infrared using a CO2 laser seed. Both the SASE and HGHG work will be extended into the VUV at the Source Development Laboratory (SDL), using the NISUS wiggler.

Another feature, made necessary by the low energy, is the use of a very short period undulator. It is clear that to make use of lower emittance electron beams short period undulators must be developed. The SAE measurement at the ATF was made with an undulator built by MIT with a period of 8.8 mm. Another undulator, with the same period but using a superconducting magnet, was developed by the NSLS. These are the shortest period undulators in actual use anywhere.

Using the MIT microundulator and the ATF beam, scientist from the ATF, MIT and LBL measured for the first time spectral spikes in the spontaneous emission of the microundulator. These fundamental shot noise-driven fluctuations in the incoherent radiation carry information about longitudinal and transverse phase space of the beam.

Measurements in other fields that have been recently completed at the ATF include work by Russian scientists on an ultra-high precision single-shot beam position monitors. The monitors demonstrated two axis beam position measurement to a resolution of 150 nm for a 0.5 nC beam pulse. Scientists led by BNL's AGS department and Instrumentation Division have demonstrated an optical ultra-fast particle detector. Scientists from Columbia and Yale started measurements of a novel dielectric wake field accelerator.

The ATF and the NSLS are in the center of the national effort to develop short wavelength FELs, and effort that at this time encompasses also SSRL, APS, TJNAF and universities. Whenever possible, we have collaborated with other laboratories, as exemplified by the highly successful ''Next Generation Photocathode RF Gun" developed with SLAC and UCLA, the SASE and HGHG experiments at the ATF being developed with ANL using a wiggler from Cornell, as well as collaboration with industry. In the near future, an exciting new experiment is being proposed for the ATF. This is the VISA experiment (short for Visible SASE). It is planned as a collaboration of BNL (NSLS), UCLA, SLAC (SSRL), LLNL and LANL. In this experiment a four meter long wiggler with a period of 1.8 cm will be installed early 1999 at the ATF to produce SASE to saturation at visible wavelengths. This experiment is considered by SSRL as an important milestone on the way to a hard x-ray FEL. Following the experiment at the ATF, the wiggler will be increased in length to six meters and installed at the SDL to extend the experiment to the VUV at about 100 nm.■